Monte Carlo study of gg→H+jets contribution to Vector Boson Fusion Higgs production at the LHC

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Abstract

The contribution of $gg \to H + jets$ production process to the vector boson fusion production of the Higgs boson, $VV \to H$, was evaluated with the ALPGEN generator and the PYTHIA shower Monte Carlo including a jet-parton matching procedure. After the experimental like event selections applied at PYTHIA particle level, the contribution was found to be 4-5 % for a Higgs boson mass of 120 GeV.

1 Introduction

The cross section measurements of the Higgs boson production in the vector boson fusion (VBF) process at LHC, $VV \rightarrow H$ ($qq \rightarrow qqH$), followed by Higgs boson decays into $\tau\tau$, WW and $\gamma\gamma$ will significantly extend the possibility of Higgs boson coupling measurements [1, 2]. According to the latest full simulation CMS results [3] the most promising VBF channel in the Higgs boson mass range of 115-135 GeV is $qq \rightarrow qqH,\ H \rightarrow \tau\tau$ [4]. For the higher Higgs boson mass the best VBF channels in CMS are $H \rightarrow WW^* \rightarrow \ell\ell\nu\nu$ [5] and $H \rightarrow WW^* \rightarrow \ell\nu$jj [6].

The uncertainty of the coupling measurement using VBF channels will depend on the contribution of $gg \rightarrow H + jets$ process after event selections. The parton level, leading order calculations [7, 8, 9] have shown that the fraction of selected events due to this process can be as large as 30% after VBF selections for a Higgs boson mass of 120 GeV. The effect of QCD corrections to $gg \rightarrow H +$ jj process in the Higgs boson mass region of 115-160 GeV was found to be 15-26 % before VBF selections and 30-40 % after η separation between two highest p_T jets was applied [10].

We present a new estimate of the contribution of the $gg \rightarrow H + jets$ process using the ALPGEN [11] generator with the MLM prescription for jet-parton matching [12, 13] at the PYTHIA shower simulation [14] in the case in which the Higgs boson mass is 120 GeV.

2 Event generation and simulation

The VBF Higgs boson production was generated with the PYTHIA version 6.409. The leading order (LO) cross section of $qq \rightarrow qqH$ process given by PYTHIA is 4.22 pb. The $gg \rightarrow H + jets$ production was generated using ALPGEN version 2.06 with the MLM prescription for jet-parton matching. The parton shower simulation was performed using PYTHIA 6.409. The CTEQ5L PDF was used in both ALPGEN and PYTHIA as well as the default values of the factorization and renormalization scales.

The parton level cuts applied in the ALPGEN generation are $p_t^j > 20$ GeV, $|\eta^j| < 5$ and $\Delta r_{jj} > 0.5$. In the case of the H + n jets (n $\geq$ 2) generation, "soft" VBF phase space preselections at the parton level were applied:

- $M_{j1j2} > 600$ GeV
- $|\Delta\eta^{j1j2}| > 4$,

where M_{j1j2} is the invariant mass and $\Delta\eta^{j1j2}$ is the difference in pseudorapidity of the two leading p_T partons. The parameters for MLM jet-parton matching were: E_T^{clus}=20 GeV, R^{clus}=0.5 and $\eta^{cl\ max}$ =5.0.

The jets at particle level, after showering and hadronization in PYTHIA, were found with the simple cone algorithm implemented in PYTHIA routine PYCELL. The parameters of the PYCELL jet finder are the following: the cone size is 0.5, the seed threshold is 2 GeV, the pseudorapidity coverage is 5.0 and the cell size in $\Delta\eta \times \Delta\phi$ is $\sim$ 0.1 $\times$ 0.1 (granularity of the CMS hadron calorimeter).

For the PYTHIA underlying event model the Tune DWT [15] was used and the stability of the results were checked with the Tune A [16]. The PYTHIA parameters for both Tunes are listed in Table 1.

The number of ALPGEN generated $gg \rightarrow H + jets$ events and cross sections given by ALPGEN are shown in Table 2.

The ALPGEN generated events were passed through the MLM jet-parton matching procedure to avoid double counting. Table 3 shows the number of selected events for a given matching type, matching efficiency and cross sections after matching.

3 Event selection

The final VBF selections used in a full simulation analysis [4] were applied to the PYTHIA particle level jets. An event must have at least two leading E_T jets that satisfy the following requirements:

- $E_T^j > 30$ GeV
- $\eta^j < 4.5$

- $M_{j1j2} > 1000$ GeV
- $|\Delta\eta^{j1j2}| > 4.5$
- $\eta^{j1} \times \eta^{j2} < 0.$

where j1 and j2 are two leading E_T jets ordered in E_T.

The effect of applying a central jet veto was studied. The central jet veto requires to reject events with a third jet that satisfies

- $E_T^{j3} > 30$ GeV
- $\eta^{j\ min} + 0.5 < \eta^{j3} < \eta^{j\ max} - 0.5$,

where $\eta^{j\ min}$ and $\eta^{j\ max}$ are the minimum and maximum η of the two leading jets (j1 and j2).

4 Results

The cross section after VBF selections for $qq \rightarrow qqH$ is 492.3 fb and for $gg \rightarrow H + jets$ is 31.3 fb, thus the contamination of $gg \rightarrow H + jets$ events after VBF selections is $\sim$ 6%. The differential cross sections after VBF selections as a function of M_{j1j2}, $|\Delta\eta^{j1j2}|$ and $\Delta\phi^{j1j2}$ (azimuthal angle between the two jets in the transverse plane) are shown in Figure 1 for both processes. The differential cross sections for $gg \rightarrow H + jets$ process shown in Figure 1 are multiplied by a factor 5. The $\Delta\phi^{j1j2}$ distribution reflects the tensor structure of the couplings to vector bosons or gluons and can be used as a probe CP property of the couplings as proposed in [17], [18], [19]. The azimutal correlations between the two jets in $gg \rightarrow H +$ jj process were found unchanged at NLO [10].

The E_T and η distributions of the two leading jets (j1 and j2) after VBF selections are presented in Figure 2 normalized by the cross sections. The η distribution for $gg \rightarrow H + jets$ process is shown multiplied by a factor 5.

One of the key features of VBF Higgs boson production is, the so-called rapidity gap, due to an absence of the color exchange in the t-channel [20], [21], [22]. It leads to the lack of the jet activity in the central detector region in contrast to the background processes to VBF Higgs boson: $t\bar{t}$, QCD Z+jets, QCD WW+jets. The central jet veto was proposed as a tool to suppress background both for heavy [23] and light [24] Higgs boson searches. The efficiency of the central jet veto for $gg \rightarrow H + jets$ events was evaluated. Figure 3 shows the E_T and η_Z distribution of the third, highest E_T jet in the event with $E_T^{j3} > 30$ GeV and in the pseudo-rapidity interval $\eta^{j\ min} + 0.5 < \eta^{j3} < \eta^{j\ max} - 0.5$ after VBF selections. The η_Z is defined as $\eta_Z = \eta^{j3} - 0.5(\eta^{j1} + \eta^{j2})$.

The total cross sections after VBF selections and the central jet veto is 468.3 fb for $qq \rightarrow qqH$ and 16.4 fb for $gg \rightarrow H + jets$, thus efficiency of the central jet veto for the "signal" VBF events is 0.95 and for the "background" ($gg \rightarrow H + jets$) events is 0.52. After the central jet veto, the contamination of $gg \rightarrow H + jets$ events is reduced from 6% (after VBF selections) to 4 %. The fraction of the $gg \rightarrow H + 1\ jet$ cross section to the total $gg \rightarrow H + jets$

Table 1: Underlying Event Tunes used in PYTHIA

Parameter	Tune A	Tune DWT
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	1.9409 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	1.0
PARP(86)	0.95	1.0
PARP(89)	1.8 TeV	1.96 TeV
PARP(90)	0.25	0.16
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	2.5

Table 2: The number of ALPGEN generated $gg \rightarrow H + jets$ events and cross sections given by ALPGEN.

Sample	N generated events	VBF preselection	σ (pb)
H + 1 jet	329196	No	19.54
H + 2 jets	26825	Yes	0.693
H + 3 jets	5513	Yes	0.574
H + 4 jets	1326	Yes	0.355

Table 3: The MLM matching type, number of selected events, matching efficiency and cross-sections.

Sample	matching type	N selected events	matching efficiency	σ (fb)
H + 1 jet	exclusive	100000	0.30	5936
H + 2 jets	exclusive	2307	0.09	59.7
H + 3 jets	exclusive	333	0.06	34.7
H + 4 jets	inclusive	224	0.17	60.1

cross section is found to be only $\sim$ 1% (0.24 fb). The differential cross sections after VBF selections and central jet veto as a function of M_{j1j2}, $|\Delta\eta^{j1j2}|$ and $\Delta\phi^{j1j2}$ are shown in Figure 4. The differential cross sections for $gg \rightarrow H + jets$ process shown in Figure 4 are multiplied by a factor 5.

4.1 Stability check of the ALPGEN results

The $gg \rightarrow H + jets$ cross sections after VBF selections and central jet veto reported in the previous section were obtained using the H+1jet to H+4jet ALPGEN samples with ”soft” VBF preselections at generation (parton) level. As a cross check the cross sections were also evaluated using the H+1jet to H+3jet ALPGEN samples. Using the H+1jet to H+3jet samples only the cross section increased from 31.3 fb to 39.8 fb after VBF selections and from 16.4 fb to 20.0 fb after VBF selections plus central jet veto.

For the case where H+1jet to H+3jet samples were used, the cross sections obtained with ”soft” VBF preselections at parton level and with no preselections were compared. With no preselections the cross section increased from 20.0 fb to 24.6 fb after final VBF selections and central jet veto. The results are summarized in Table 4.

Finally, results were re-evaluated with PYTHIA Tune A [16] and differences at the level less that 1 % with Tune DWT [15] were found.

5 Conclusion

The contribution of $gg \rightarrow H + jets$ events to the $gg \rightarrow qqH$ events after VBF selections and central jet veto was estimated to be $\sim$ 4-5 % for a Higgs boson mass of 120 GeV. The result is stable within $\sim$ 25 % to the usage or not of the ”soft” VBF preselection and within $\sim$ 20 % when ALPGEN samples are generated up to 3 or 4 jets. No effect on the results was found when PYTHIA Tune DWT or Tune A were used.

Table 4: Stability check of the results obtained with ALPGEN

VBF preselection	Samples	$\sigma(ggH)$ (fb)	$\sigma(ggH)/\sigma(qqH)$
	After VBF selection		
Yes	H+1jet(exc)+H+2jet(exc)+H+3jet(exc)+H+4jet(inc)	31.3	0.06
Yes	H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	39.8	0.08
	After VBF selection and Central jet veto		
Yes	H+1jet(exc)+H+2jet(exc)+H+3jet(exc)+H+4jet(inc)	16.4	0.04
Yes	H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	20.0	0.04
No	H+1jet(exc)+H+2jet(exc)+H+3jet(inc)	24.6	0.05

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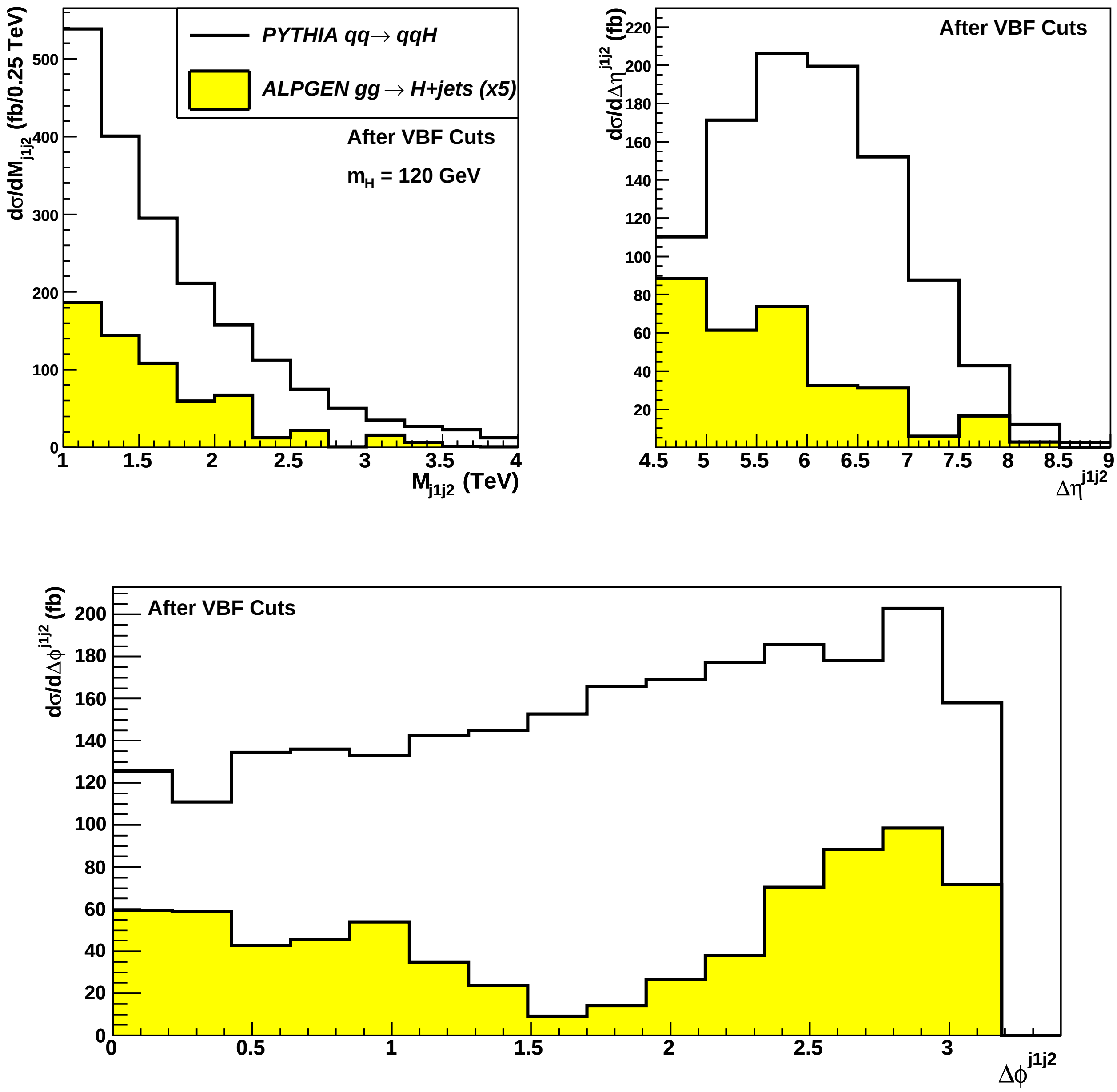

Figure 1: The differential cross section as a function of M_{j1j2} (upper left plot), $|\Delta\eta^{j1j2}|$ (upper right plot) and $\Delta\phi^{j1j2}$ (bottom plot) for $qq \to qqH$ process (solid histogram) and $gg \to H + jets$ process (shaded histogram) after VBF selections. The cross sections for $gg \to H + jets$ process are shown multiplied by a factor 5.

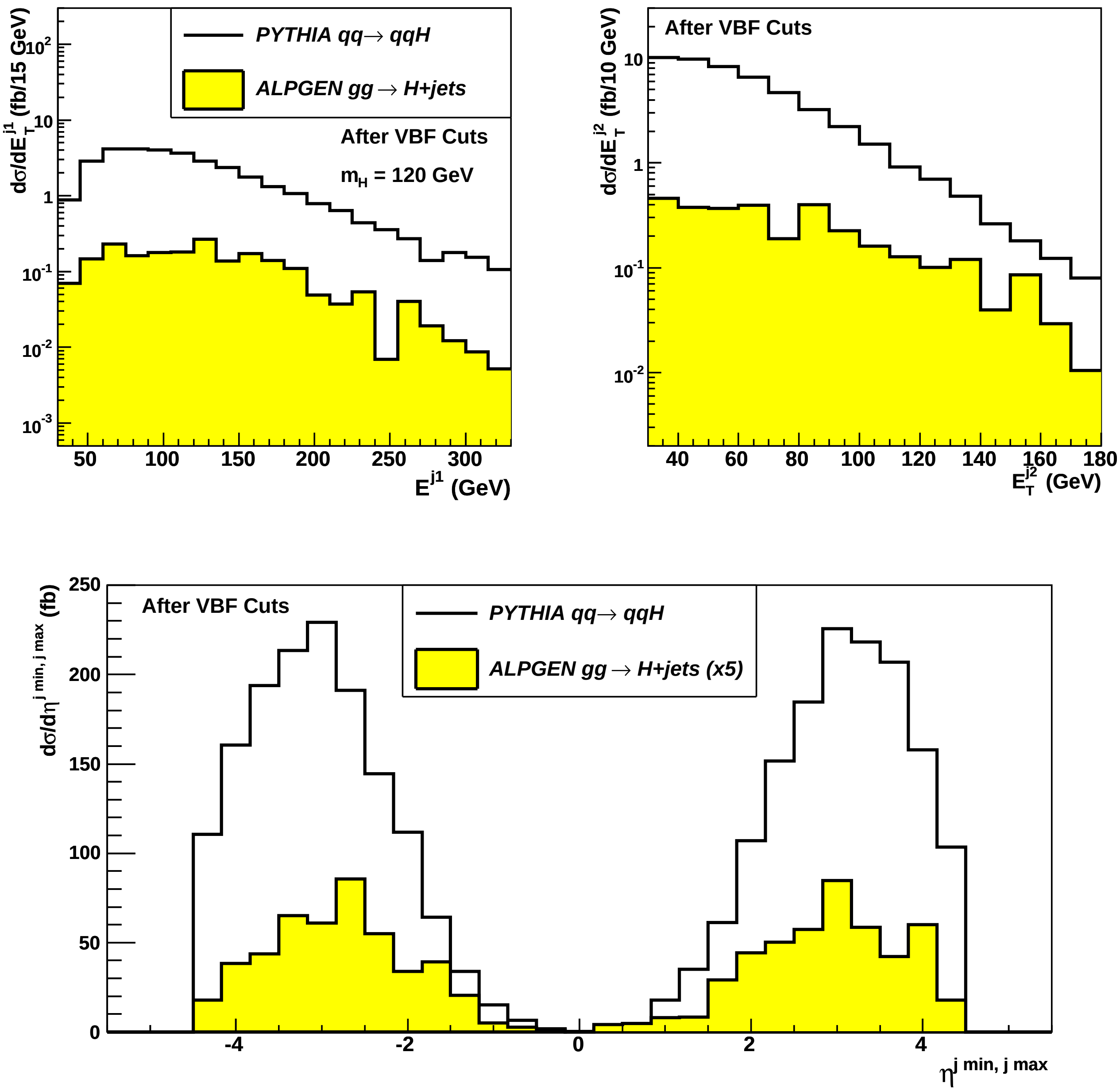

Figure 2: The E_T and η distributions of the two leading E_T jets (j1 and j2) for $qq \to qqH$ process (solid histogram) and $gg \to H + jets$ process (shaded histogram) after VBF selections. The bottom plot shows η distributions of the j1 and j2 with minimal ($\eta^{j\ min}$) and maximal ($\eta^{j\ max}$) pseudorapidity, where the cross section for $gg \to H + jets$ process is shown multiplied by a factor 5.

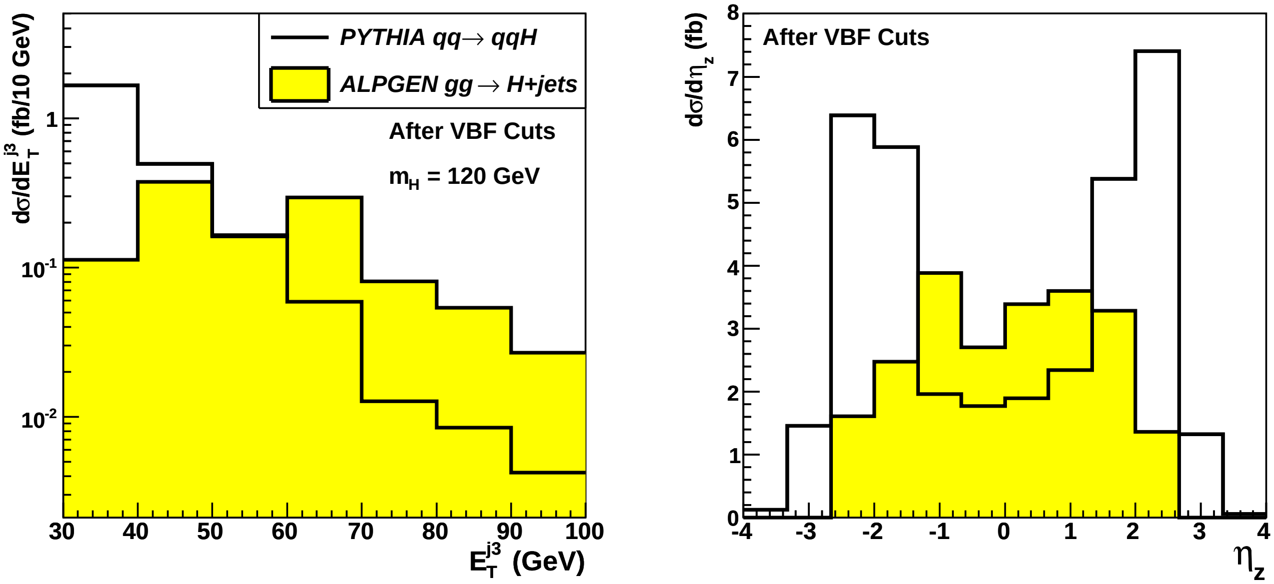

Figure 3: The E_T and η_Z distribution of the third jet (j3) for $qq \to qqH$ process (solid histogram) and $gg \to H + jets$ process (shaded histogram) after VBF selections. The η_Z is defined as $\eta_Z = \eta^{j3} - 0.5(\eta^{j1} + \eta^{j2})$.

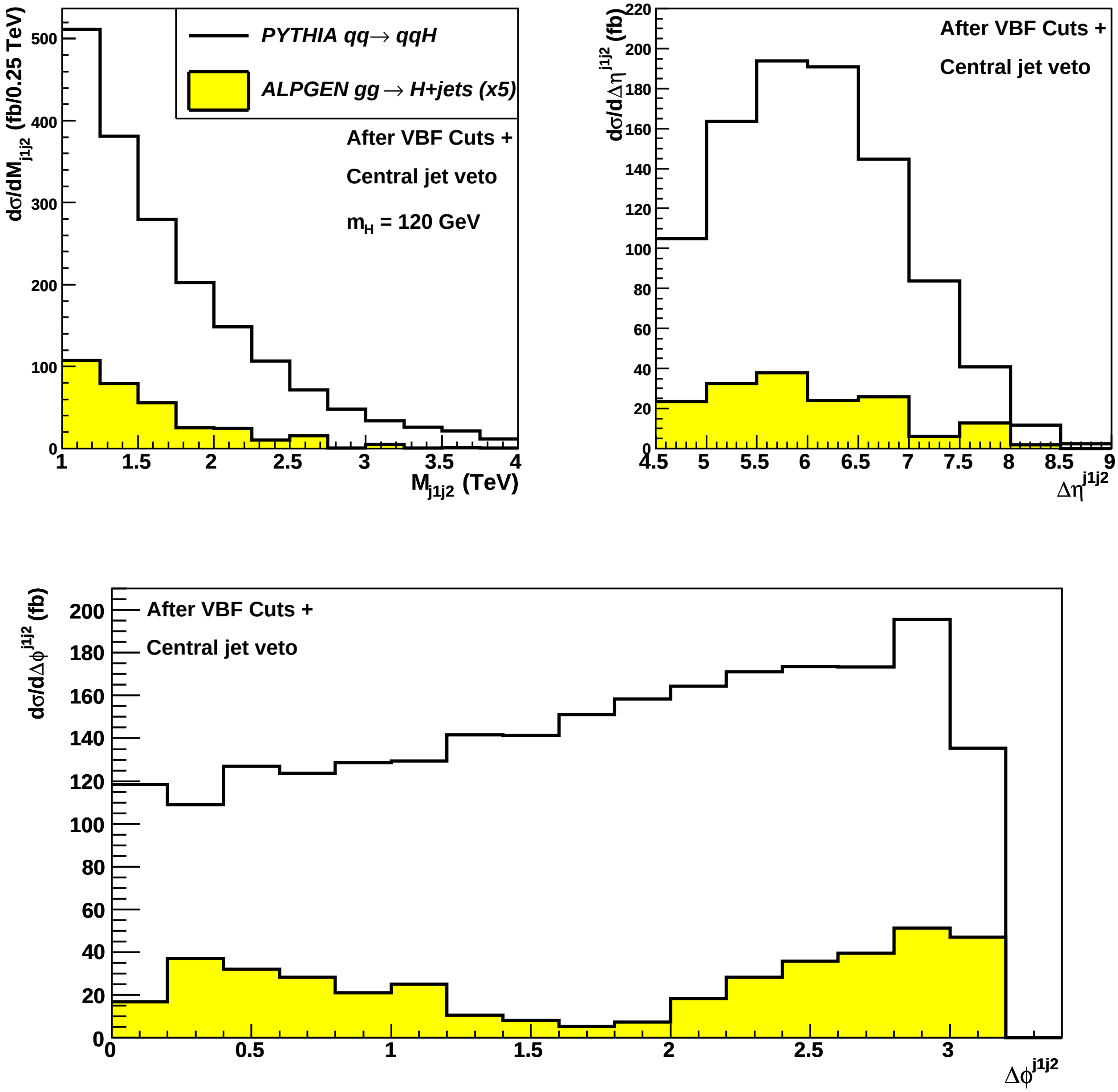

Figure 4: The same as Figure 1, but after VBF and central jet veto selections.